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A numerical tropical cyclone wind wave model for the western North Pacific is presented and the results are compared with observational analyses of tropical cyclones. The wind input for the model is based on information that would be readily available or easily derived. The results of this preliminary examination show good agreement between the model sea state output and the observational data.

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          show good agreement between the model sea state output
          and the observational data. (Author)
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A WIND WAVE TROPICAL CYCLONE MODEL FOR THE WESTERN NORTH PACIFIC OCEAN

BY

SAMSON BRAND, KEVIN RABE AND TAIVO LAEVASTU

AUGUST 1976

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CONTENTS

1. INTRODUCTION

One of the most difficult analyses the Navy forecaster is concerned with is the sea-height analysis, especially when a tropical cyclone is present on his map. The problem is caused by: (1) the lack of data surrounding tropical cyclones; (2) subjective observations; and (3) subjective analyses. An attempt is made in this paper to resolve part of the problem by establishing a more objective method to define the state of the sea about tropical cyclones by means of a numerical tropical cyclone wind wave model. The intent is to try to improve the product and make it more consistent. The inconsistencies in the sea-height analysis of separate meteorological/oceanographic centers have been previously discussed by Brand et al. (1975) and they emphasize the need for a more objective way to define the sea state about tropical cyclones -- to.say nothing about the forecast problem, which is highly dependent on the initial analysis.

Ship captains and ship routing officials are seriously concerned with sea states around tropical cyclones, since sea conditions affecting storm evasion or ship movement can cover a much larger area than the wind associated with the storm. A miscalculation concerning a building sea condition could lead to a dangerous rendezvous with a tropical cyclone.

Ship captains are aware that any encounter with high sea states increases the probability of damage and that this damage is highly correlated with sea conditions (see Table 1). A miscalculation concerning sea conditions also impacts on the planning and execution of tactical operations and, in addition, impedes the effectiveness of ship routing of Department of Defense contracted vessels which equals to an approximate DOD cost of $10,000.00 for each day of lost time (Brand and Blelloch, 1975).

Table 1. The expected damage costs associated with sea height for U.S. Navy ships (other than small craft) based on Navy Safety Center records for the period 1969-75. Present day damage would have to take into consideration inflationary increases in costs (Lulejian et al., 1976).

Sea Height X in Meters (Feet)					Expected Damage Costs (dollars)
	(0)	$\leq$ X <	1.2	(4)	. . . . . .$ 0
1.2	(4)	$\leq$ X <	2.4	(8)	 2
2.4	(8)	$\leq$ X <	3.7	(12)	 14
3.7	(12)	$\leq$ X <	4.9	(16)	 41
4.9	(16)	$\leq$ X <	6.1	(20)	 537
6.1	(20)	$\leq$ X <	7.3	(24)	 3,172
7.3	(24)	$\leq$ X <	8.5	(28)	 7,656
		X $\geq$	8.5	(28)	 34,145

2. THE WIND WAVE MODEL

The French spectroangular wave model (DSA V) as described by Gelci et al. (1963) and Devillaz (1967) formed the basis for the numerical investigation. The model was selected because of its spacial growth and decay features and its treatment of angular advection and dispersion. In simplified physical form, the change in spectral density of the model is related to a spectral growth term, a decay term and an advective term. The spectral growth term utilizes the components of the wind as its only driving force. Decay is accounted for by the interaction of the sea state components and an empirical damping coefficient. The advection term is a function of the gradient of the spectral densities between points and the unit speed of a swell packet.

A grid containing 957 grid points (33 x 29) with a 74 km (40 n mi) grid interval was constructed for the study. The fixed grid area [2446 km (1320 n mi) east-west and 2068 km (1160 n mi) north-south] was large enough to describe the sea state for a number of days even for the fastest and largest of western North Pacific Ocean tropical cyclones.

A logarithmic tropical cyclone wind profile (USAF, 1972)[1] was used to initialize and thereafter drive the wind wave model. The only input necessary was radius to maximum wind, maximum wind and radius to environmental or background flow (related to tropical cyclone circulation size).

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[1]The equation is in the form,

$$V = V_m + \left[\frac{V_m - V_s}{\ln \frac{r_m}{r_s}}\right] \ln \frac{r}{r_m} \, ,$$

where V_m is the maximum wind, r_m is the radius to maximum wind, V_s is the background wind at the distance r_s, and V is the wind at any point between r_m and r_s at a radius r.

The wind distribution asymmetry around the tropical cyclone was arrived at by adding the input storm movement to the symmetrical wind profile. It should be noted that the input information necessary to run the model is oriented toward tropical cyclone warning and synoptic information available to the forecaster. Thus the model can be run not only diagnostically but also in the forecast mode by inserting the tropical cyclone forecast information. The results of some numerical experiments and their comparisons with observational results are discussed in Section 3.

3. DISCUSSION OF RESULTS

A number of experiments were run to determine if the model output resembled observational analyses. Once credibility in the model was established, a number of experiments were conducted to determine the sensitivity of the wind wave model to tropical cyclones with different characteristics; i.e., small versus large, slow versus fast, and rapidly intensifying or slowly intensifying tropical cyclones. Most runs were continued out 111 hr (approximately 20 minutes of CDC 6500 run time) after being initialized at $t = 0$ hr with a small weak tropical cyclone of 18.0 ms^{-1} (35 kt) maximum wind and a circulation size of 463 km (250 n mi). The circulation size is the distance radially outward from the storm center that limits the tropical cyclone wind distribution to the set value. It can also be thought of as the distance to the background or environmental wind outside the storm circulation.

The first experiment to be presented is shown in Figure 1. The tropical cyclone input parameters from $t = 0$ to $t = 96$ hr are also shown. Tropical cyclone input information for this and in future cases is inserted at 24-hr intervals. Computations concerning the sea state are derived at 3-hr intervals and the one shown here is at $t = 111$ hr or 15 hr after the $t = 96$ hr tropical cyclone information has been inserted into the model. The sea state presented is the significant wave height or the average height of the highest one third of the waves. The storm in Figure 1 intensifies from 18 ms^{-1} (35 kt) to 46.3 ms^{-1} (90 kt) in 96 hr. The speed of movement is a constant 6.3 ms^{-1} (12.3 kt) in a west-northwesterly direction and the circulation size increases from 463 km (250 n mi) to 834 km (450 n mi) in 96 hr. The radius to maximum wind was set as 74 km (40 n mi) and the wind input for any grid points found within the "eye" were set to a value equal to speed and direction of the storm movement. For the purposes of this study, this case will be called the "average" storm.

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The wind field (Figure 1(a)) looks quite representative for a 46.3 ms^{-1} (90 kt) maximum wind tropical cyclone with stronger winds in the right semicircle and with a realistic isotach pattern. The resulting sea state pattern [2.7-4.6 m (9-15 ft) range][2] at t = 111 hr also looks encouraging with the greatest area of stronger seas to the right and rear of the storm. This has also been documented observationally (Arakawa and Suda, 1953; Arakawa, 1954; Unoki, 1957; and Brand et al., 1974).

TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	6.3 ms^{-1} (12.3 kt)	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	6.3 ms^{-1} (12.3 kt)	556 km (300 n mi)
48	28.3 ms^{-1} (55 kt)	6.3 ms^{-1} (12.3 kt)	649 km (350 n mi)
72	36.0 ms^{-1} (70 kt)	6.3 ms^{-1} (12.3 kt)	741 km (400 n mi)
96	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)

Figure 1. Wind wave model results at t = 111 hr for tropical cyclone isotach distribution (a) and significant sea height (b). Tropical cyclone input parameters are also shown. The wind distribution near the storm center is not shown.

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[2]Only the sea state in the range 2.7-4.6 m (9-15 ft) will be examined. It was felt that conclusions could not be drawn for significant sea heights >4.6 m (15 ft) because of the limitations and resolution of the model. In addition observational comparisons are difficult with high sea states. Verploegh (1961) estimated the average observational error for a visual observation of wave height varies from 1 ft at 5 ft wave heights to 3 ft at 18 ft wave heights.

The radially averaged sea height for the model tropical cyclone was compared
with sea height values of empirical and also operationally produced western
North Pacific tropical cyclone analyses [Optimum Track Ship Routing (OTSR) at
Fleet Numerical Weather Central, Monterey and Fleet Weather Central, Guam]
(see Figure 2). The empirical values (H.O. 604) have been derived from wave
height and wind speed empirical relationships (U.S. Naval Oceanographic Office,
1966) incorporating a number of necessary assumptions because of the small scale
of tropical cyclones. The model tropical cyclone in the 2.7-4.6 m (9-15 ft)
range compares favorably with the observational and empirical results for
similar intensity tropical cyclones.[3]

With this encouraging first step, the stage was set for additional runs to
test the sensitivity of the model to input tropical cyclone variations.
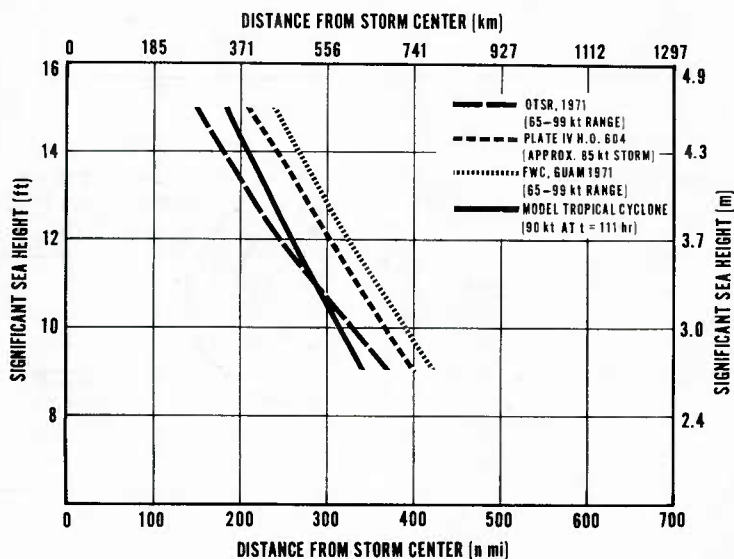
Figure 2. Comparisons of
the sea height around
tropical cyclones in
the western North
Pacific for a similar
intensity category.

a.   Small Versus Large Tropical Cyclones

Figure 3 shows the results of the experiment at t = 111 hr for a small
tropical cyclone (Figure 3(a) and (b)) and a large tropical cyclone (Figure 3(c)
and (d)). The small tropical cyclone grows in circulation size from 463 km
(250 n mi) at t = 0 to 649 km (350 n mi) at t = 96, while the large storm grows
from 463 km (250 n mi) to 1205 km (650 n mi) in the same time frame. All other
tropical cyclone parameters are similar.

_____

[3]It should be noted that the OTSR and FWC values are reduced from wave
height analyses derived from data available for the 1971 tropical cyclone season
(Brand et al., 1974).

TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind).	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	6.3 ms^{-1} (12.3 kt)	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	6.3 ms^{-1} (12.3 kt)	510 km (275 n mi)
48	28.3 ms^{-1} (55 kt)	6.3 ms^{-1} (12.3 kt)	556 km (300 n mi)
72	36.0 ms^{-1} (70 kt)	6.3 ms^{-1} (12.3 kt)	602 km (325 n mi)
96	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	649 km (350 n mi)
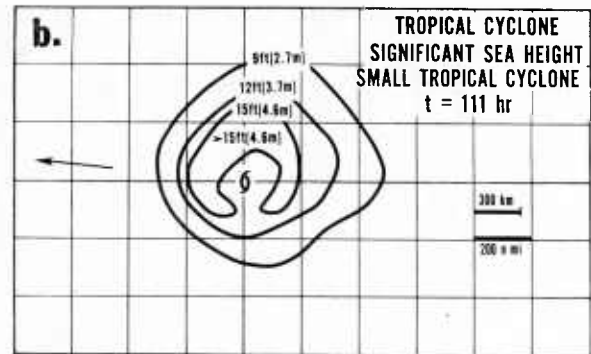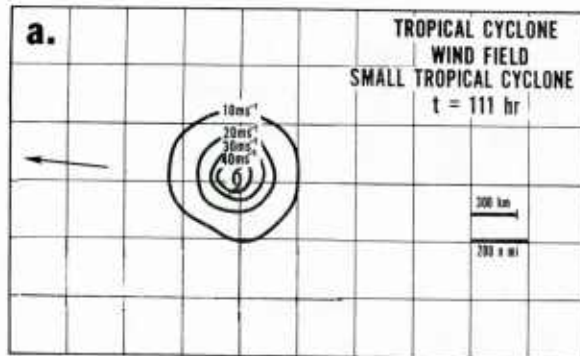
TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	6.3 ms^{-1} (12.3 kt)	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	6.3 ms^{-1} (12.3 kt)	649 km (350 n mi)
48	28.3 ms^{-1} (55 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
72	36.0 ms^{-1} (70 kt)	6.3 ms^{-1} (12.3 kt)	1019 km (550 n mi)
96	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	1205 km (650 n mi)
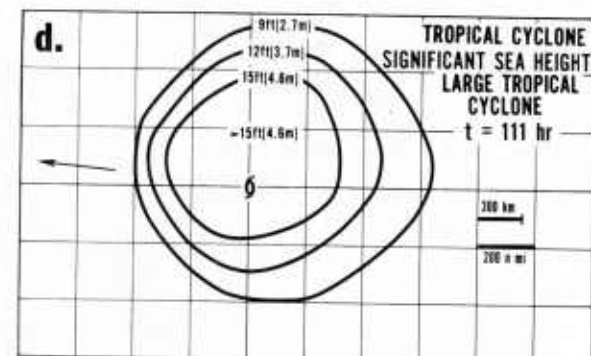
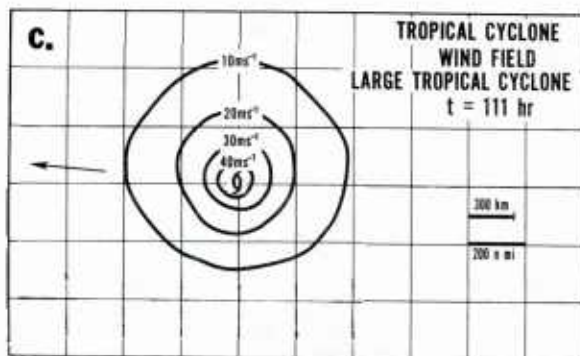Figure 3. Wind wave model results at t = 111 hr for a small tropical cyclone [(a) and (b)] and a large tropical cyclone [(c) and (d)]. Tropical cyclone input parameters are also shown. Distributions near the storm center are not shown.

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The resulting sea state differences are quite dramatic as seen when radially averaged and plotted on Figure 4. For reference, the "average" tropical cyclone is also plotted. Notice the "large" model tropical cyclone produces significant seas of 3 m (10 ft) nearly 700 km (380 n mi) from the storm center, while the small storm (same intensity) produces 3 m (10 ft) seas about 500 km (270 n mi) from the storm center.

Figure 5 presents a comparison of the radially averaged wind profiles for the small, large, and average tropical cyclones at t = 111 hr. In addition, the tangential wind distribution about the center of a number of typhoons (Hughes, 1952) is also shown. The logarithmic wind profiles of the model were set at a radius of maximum wind of 74 km (40 n mi). In comparing the profiles it should be noted that the model values would be slightly less if just the tangential wind component were examined. The streamline field is discussed in Section 4.
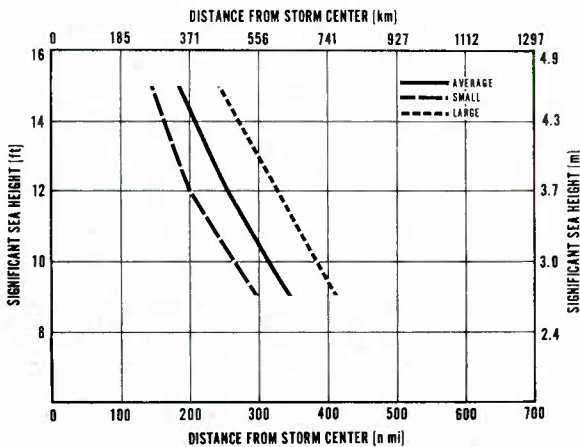
Figure 4. The radially averaged significant sea height [2.7–4.6 m (9-15 ft) range] for the small and large tropical cyclones (Figure 3) and the "average" tropical cyclone (Figure 1).
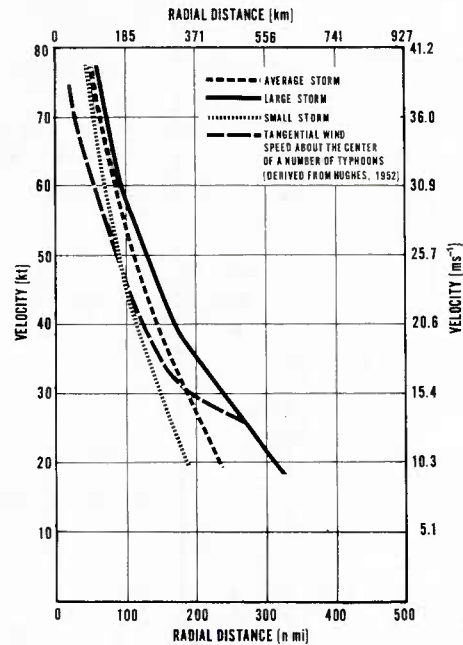
Figure 5. Comparisons of the radially averaged wind profiles for the small, large and average tropical cyclones (t = 111 hr) and the tangential wind profile for a number of typhoons.

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b.   Slow Versus Fast Tropical Cyclones

Because the tropical cyclone speed of movement is added to the symmetric wind distribution to arrive at the asymmetric wind distribution, the speed of movement is related to asymmetry of the sea state distribution. Thus the faster the speed of movement, the larger the bias in the area of high seas in the right semicircle of the storm. This can be seen in Figure 6, which presents the wind field and resulting sea state for a stationary, slow [3.2 ms^{-1} (6.2 kt)] and fast [9.5 ms^{-1} (18.5 kt)] tropical cyclone. All tropical cyclone parameters are the same except for speed of movement. The radially averaged sea state values [2.7-4.6 m (9-15 ft) range] as shown in Figure 7 do not show significant differences, but the sea state asymmetries of Figure 6 show the degree of sensitivity to speed of movement.

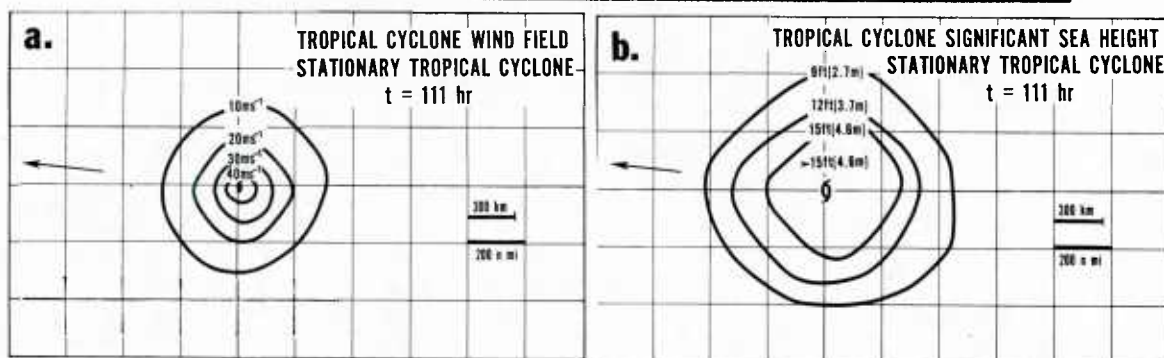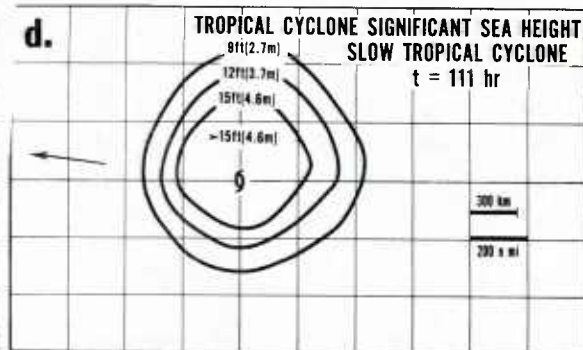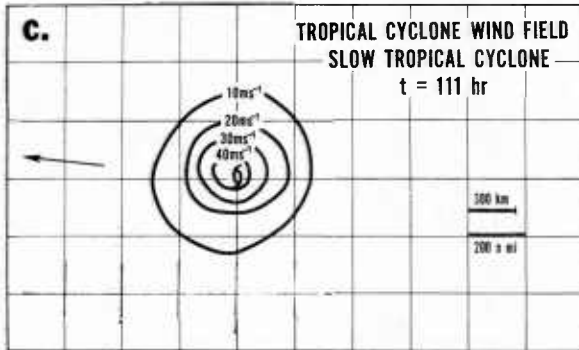| TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	0	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	0	556 km (300 n mi)
48	28.3 ms^{-1} (55 kt)	0	649 km (350 n mi)
72	36.0 ms^{-1} (70 kt)	0	741 km (400 n mi)
96	46.3 ms^{-1} (90 kt)	0	834 km (450 n mi)

Figure 6. Wind wave model results at t = 111 hr for a stationary [(a) and (b)], slow [3.2 ms^{-1} (6.2 kt)] [(c) and (d)], and fast [9.5 ms^{-1} (18.5 kt)] [(e) and (f)] tropical cyclone. Tropical cyclone input parameters are also shown. Distributions near the storm center are not shown.

TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	3.2 ms^{-1} (6.2 kt)	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	3.2 ms^{-1} (6.2 kt)	556 km (300 n mi)
48	28.3 ms^{-1} (55 kt)	3.2 ms^{-1} (6.2 kt)	649 km (350 n mi)
72	36.0 ms^{-1} (70 kt)	3.2 ms^{-1} (6.2 kt)	741 km (400 n mi)
96	46.3 ms^{-1} (90 kt)	3.2 ms^{-1} (6.2 kt)	834 km (450 n mi)

c. TROPICAL CYCLONE WIND FIELD SLOW TROPICAL CYCLONE t = 111 hr

d. TROPICAL CYCLONE SIGNIFICANT SEA HEIGHT SLOW TROPICAL CYCLONE t = 111 hr

TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	9.5 ms^{-1} (18.5 kt)	463 km (250 n mi)
24	20.1 ms^{-1} (40 kt)	9.5 ms^{-1} (18.5 kt)	556 km (300 n mi)
48	28.3 ms^{-1} (55 kt)	9.5 ms^{-1} (18.5 kt)	649 km (350 n mi)
72	36.0 ms^{-1} (70 kt)	9.5 ms^{-1} (18.5 kt)	741 km (400 n mi)
96	46.3 ms^{-1} (90 kt)	9.5 ms^{-1} (18.5 kt)	834 km (450 n mi)

e. TROPICAL CYCLONE WIND FIELD FAST TROPICAL CYCLONE t = 111 hr

f. TROPICAL CYCLONE SIGNIFICANT SEA HEIGHT FAST TROPICAL CYCLONE t = 111 hr

Figure 6 (continued)

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DISTANCE FROM STORM CENTER (km)
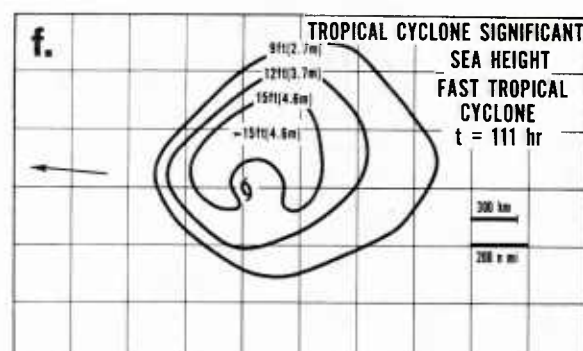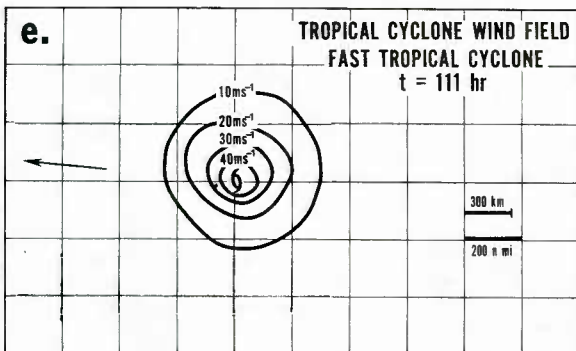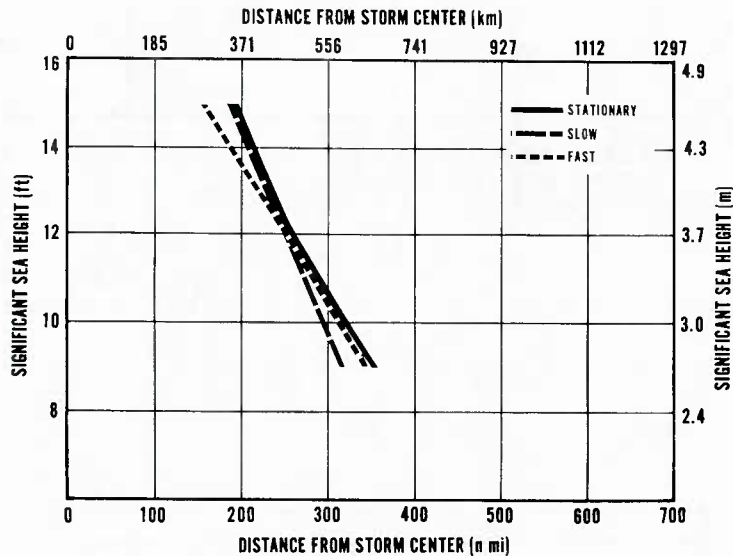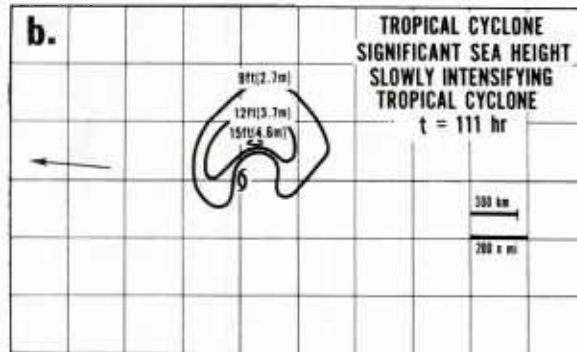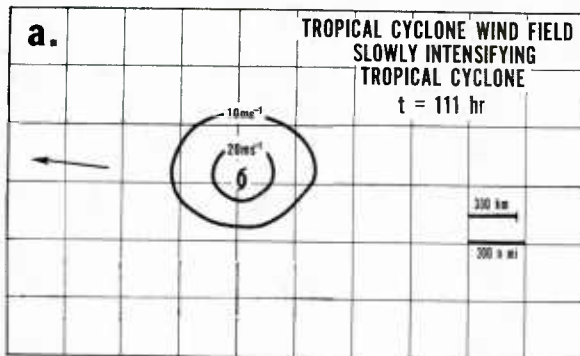

Figure 7. The radially averaged significant sea height
[2.7-4.6 m (9-15 ft) range] for the stationary, slow and
fast tropical cyclones (Figure 6).

c.   Rapidly Intensifying Versus Slowly Intensifying Tropical Cyclone

Because tropical cyclones with the same initial conditions can some-
times develop into very intense typhoons and at times intensify only to the
tropical storm stage, a test was run comparing the model output for both
conditions. The results can be seen in Figure 8, which shows a slowly
intensifying tropical cyclone [18.0 ms^{-1} (35 kt) at t = 0 to 28.3 ms^{-1} (55 kt)
after 96 hr] and a rapidly intensifying tropical cyclone [18.0 ms^{-1} (35 kt) at
t = 0 to 59.2 ms^{-1} (115 kt) after 96 hr]. The sea state as expected is
significantly different and is very sensitive to the maximum wind. See also
the radially averaged values plotted as Figure 9. Note the extreme asymmetry
in Figure 8(b). In Figure 8(d) note that the 2.7 m (9 ft) isopleth extends
outward about 1100 km (600 n mi) in the right rear quadrant.

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TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	6.3 ms^{-1} (12.3 kt)	463 km (250 n mi)
24	20.6 ms^{-1} (40 kt)	6.3 ms^{-1} (12.3 kt)	556 km (300 n mi)
48	23.2 ms^{-1} (45 kt)	6.3 ms^{-1} (12.3 kt)	649 km (350 n mi)
72	25.7 ms^{-1} (50 kt)	6.3 ms^{-1} (12.3 kt)	741 km (400 n mi)
96	28.3 ms^{-1} (55 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)

a. TROPICAL CYCLONE WIND FIELD SLOWLY INTENSIFYING TROPICAL CYCLONE t = 111 hr

b. TROPICAL CYCLONE SIGNIFICANT SEA HEIGHT SLOWLY INTENSIFYING TROPICAL CYCLONE t = 111 hr

TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	18.0 ms^{-1} (35 kt)	6.3 ms^{-1} (12.3 kt)	463 km (250 n mi)
24	28.3 ms^{-1} (55 kt)	6.3 ms^{-1} (12.3 kt)	556 km (300 n mi)
48	38.6 ms^{-1} (75 kt)	6.3 ms^{-1} (12.3 kt)	649 km (350 n mi)
72	48.9 ms^{-1} (95 kt)	6.3 ms^{-1} (12.3 kt)	741 km (400 n mi)
96	59.2 ms^{-1} (115 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)

c. TROPICAL CYCLONE WIND FIELD RAPIDLY INTENSIFYING TROPICAL CYCLONE t = 111 hr

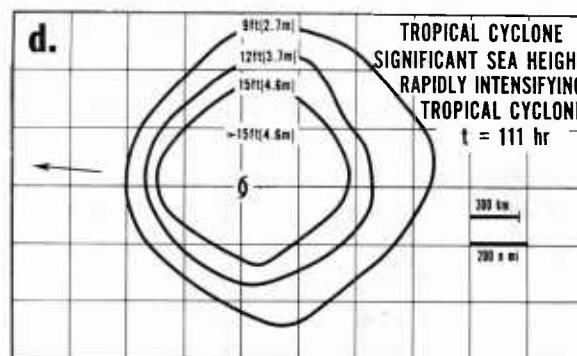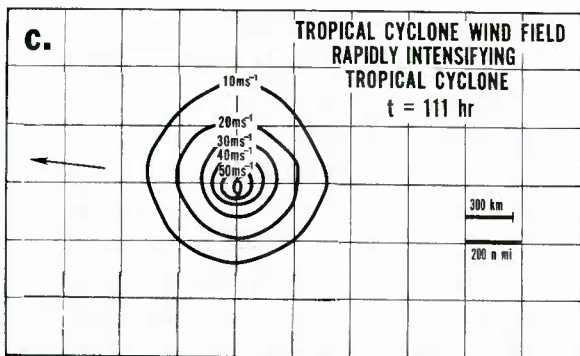d. TROPICAL CYCLONE SIGNIFICANT SEA HEIGHT RAPIDLY INTENSIFYING TROPICAL CYCLONE t = 111 hr

Figure 8. Wind wave model results at t = 111 hr for a slowly intensifying [(a) and (b)] and rapidly intensifying [(c) and (d)] tropical cyclone. Tropical cyclone input parameters are also shown. Distributions near the storm center are not shown.
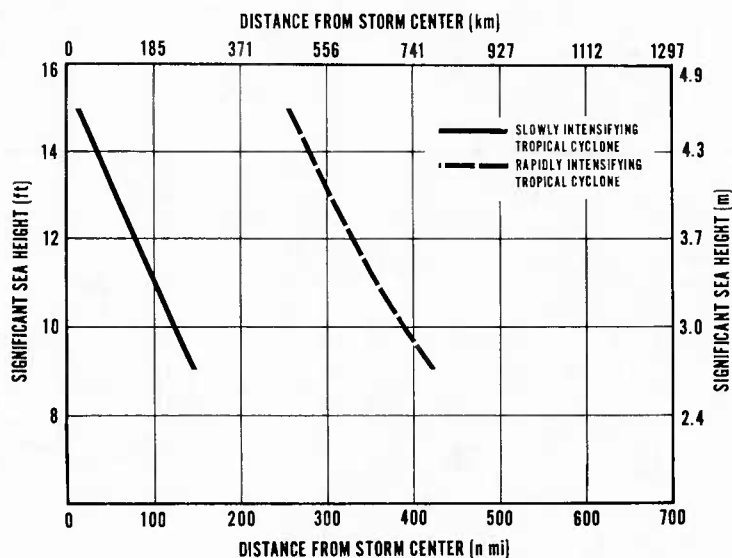
Figure 9. The radially averaged significant sea height [2.7-4.6 m (9-15 ft) range] for the slowly intensifying and rapidly intensifying tropical cyclones (Figure 8).

d.   Initialization With a 90-Kt Tropical Cyclone

Because sea states are built up by the wind, the model usually takes a number of 3-hr time steps to build the seas to what would appear realistic and stable values. In order to examine the time period for this stabilization, a test was run with the initial conditions being the values at 96 hr of the "average" storm; that is, 46.3 ms^{-1} (90 kt) as the maximum wind, 6.3 ms^{-1} (12.3 kt), the forward speed of movement (west-northwesterly direction), and a circulation size of 834 km (450 n mi). These values were maintained throughout the test. Figures 10 and 11 show the results for t = 15, 39, 63 and 111 hr. It can be seen that even after 15 hr the seas are built up to nearly the stable value, which closely approximates the "average" storm (see Figure 1). After t = 39 hr, minor variations occur. These results indicate that the model does not necessarily have to initialize as a beginning tropical depression, but can be initialized at any intensity. This not only could reduce the computational costs, but also would make the model more operationally feasible since the model could be initialized for any stage in the life cycle of a tropical cyclone.

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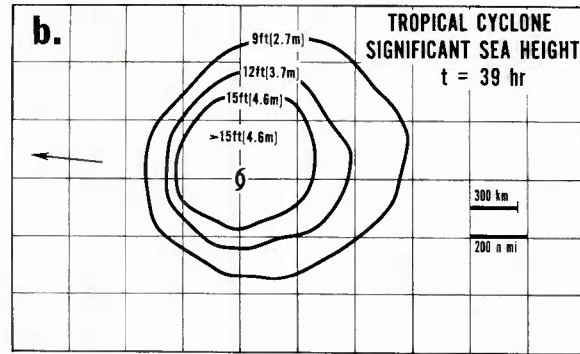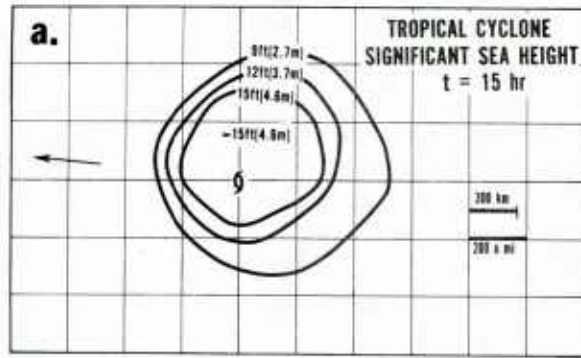| TROPICAL CYCLONE INPUT PARAMETERS			
Time (hr)	Intensity (Maximum Wind)	Speed of Movement	Circulation Size
0	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
24	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
48	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
72	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
96	46.3 ms^{-1} (90 kt)	6.3 ms^{-1} (12.3 kt)	834 km (450 n mi)
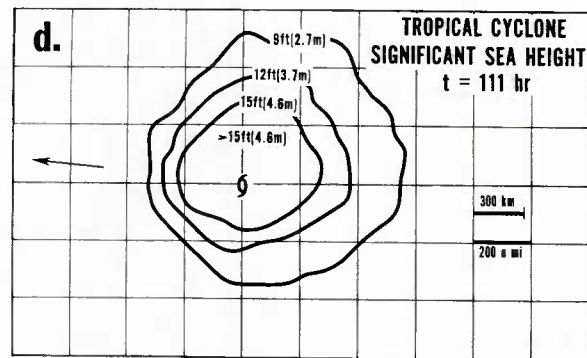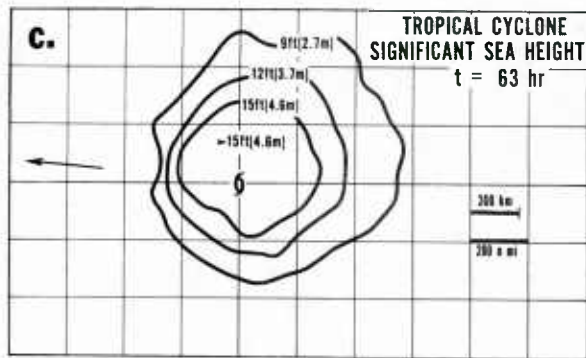
Figure 10. Wind wave model results at (a) t = 15; (b) t = 39; (c) t = 63; and (d) t = 111 hr for the indicated tropical cyclone input parameters.
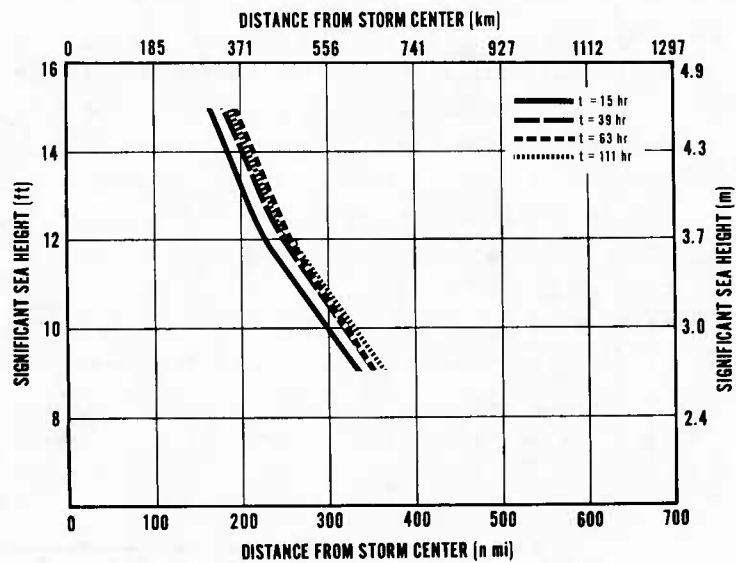
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Figure 11.   The radially averaged significant sea height
[2.7-4.6 m (9-15 ft) range] at the indicated times for
the tropical cyclone values of Figure 10.

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4. SOME ADDITIONAL CONSIDERATIONS AND FUTURE RESEARCH

The wind wave model has the capability of incorporating background or environmental flow as an input parameter. This vector would then be added to the wind distribution with a resulting new wind distribution for the entire grid including the tropical cyclone. By incorporating a small value of background flow (0.001 ms^{-1}) at a specified direction (117° for example), provides the capability of producing a streamline field as part of the output with no appreciable change in the wind or sea state field. An example of this for the "average" case is shown in Figure 11.

The wind wave model also has the capability of providing such additional output as wave period, direction and a 16 point spectral breakdown of wave energy at specified points throughout the grid. These capabilities would provide a basis for testing the model with actual observations in the western North Pacific Ocean.[4]

Figure 12. Streamline analysis for "average" tropical cyclone at t = 111 hr with background wind of 0.001 ms^{-1} at 117°.

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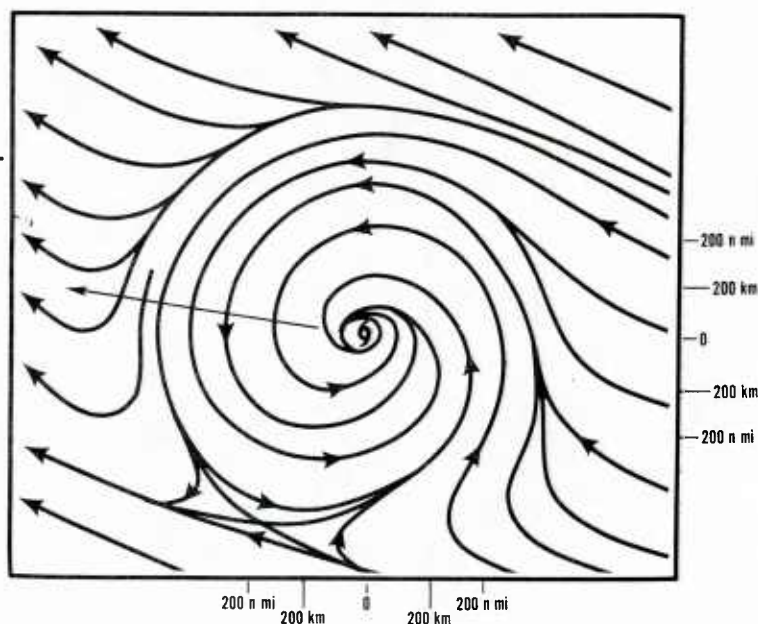
[4]This output is of concern to ship routing officials because every ship is not only sensitive to sea height but also to the direction and dominant period of the sea. For example, even a carrier could be severely operationally limited by 3.7 m (12 ft) seas if the wave period is a certain resonant frequency and direction. This natural period of oscillation varies for every type of ship.

In addition, tests could be run comparing the model output with post analysis tropical cyclone data or even real time in a semi-operational mode. Comparisons could also be made with previous sea state analyses such as that from operational analysis and forecast centers. An example is that of Typhoon Trix (000 GMT, 26 August 1971) as analyzed by Optimum Track Ship Routing (presently located at Fleet Numerical Weather Central) as shown in Figure 13. The stage of development and characteristics of Typhoon Trix at this time closely approximates the model "average" typhoon (Figure 1).
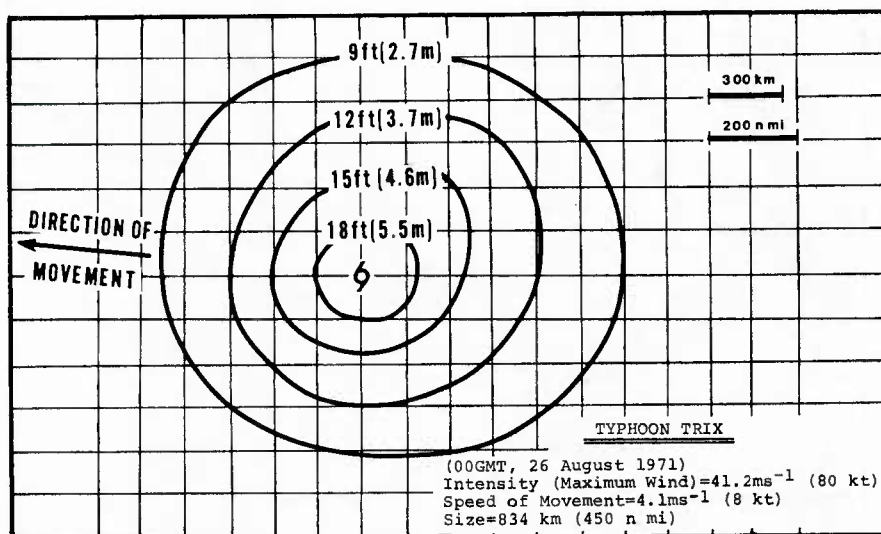

Figure 13. The sea height analysis for Typhoon Trix (0000 GMT, 26 August 1971) as produced by Optimum Track Ship Routing, Fleet Numerical Weather Central, Monterey.

The model is also not limited to the 33x29 grid as discussed earlier but has the flexibility to be expanded to provide information on recurring tropical cyclones that exist for a longer period of time and traverse a larger area than the typical east-west moving tropical cyclone. An example of the model output for a recurring tropical cyclone (from t = 0 to t = 159 hr) is shown in Figure 14.

The high resolution of the model also would be of value as a nested version in a broader ocean spectral model as is presently being run operationally at Fleet Numerical Weather Central, Monterey.
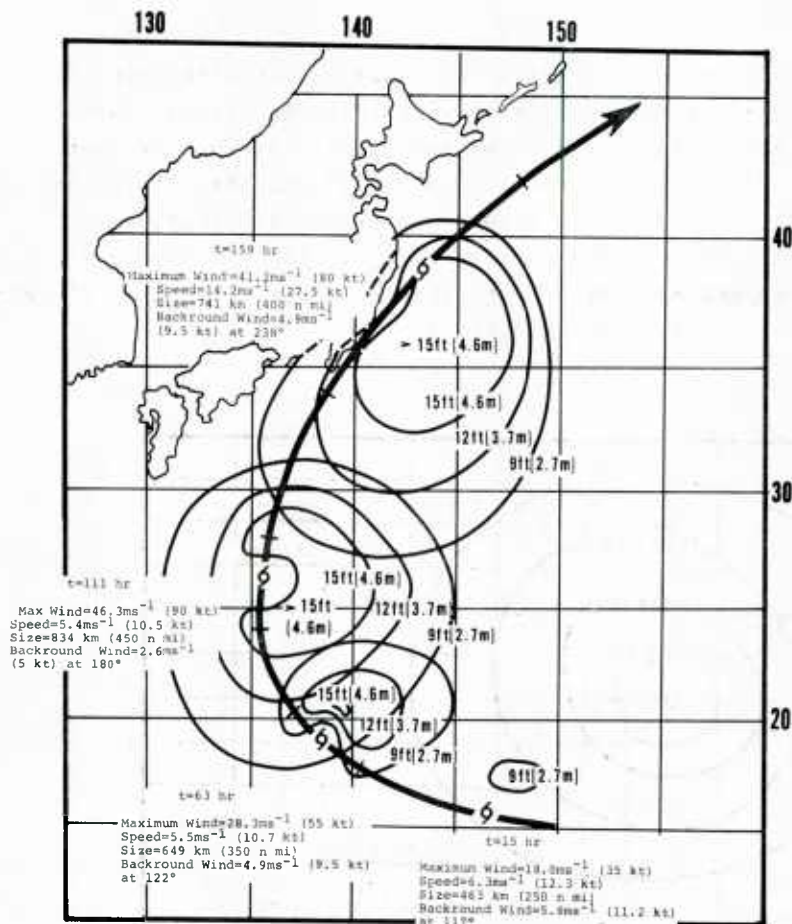
Figure 14. Wind wave model significant sea height for a recurring tropical cyclone with varying intensity, speed of movement, size and background wind as specified.

Actual test cases could perhaps be the next logical step in the evaluation of the wind wave model as an operational tool. The preliminary results are encouraging and resemble the wind and sea state distribution observed around tropical cyclones in the western North Pacific. In addition, with minor modifications the wind wave model could probably be adjusted to resemble the sea state about tropical cyclones for other regions. This may be necessary since there appears to be variations in sea state distributions around similar intensity tropical cyclones for different regions such as the South China Sea versus the western North Pacific to the east of the Philippines (Brand et al., 1974).

The wind wave model output as described here has the potential to aid the analyst or forecaster in describing the sea states about tropical cyclones in the western North Pacific using input information and parameters readily available or easily derived. This could be of value in typhoon evasion and ship routing procedures in the western North Pacific Ocean.

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